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MODERN SCIENTIFIC IDEAS

ESPECIALLY THE IDEA OF DISCONTINUITY

BEING THE EXPANDED SUBSTANCE OF SIX TALKS ON "ATOMS AND WORLDS" BROADCAST IN OCTOBER AND NOVEMBER, 1926

By

SIR OLIVER LODGE, F.R.S.

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LONDON: ERNEST BENN, LIMITED
BOUVERIE HOUSE, FLEET ST. E.C.

First published February, 1927
Second impression March, 1927
Third impression April, 1927
Fourth impression August, 1927
Fifth impression November, 1927
Sixth impression February, 1928

MADE AND PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER

DEDICATION

To all, of any age, in whom an interest in physical science is awakening, especially to those who listened to his radio-talks on Atoms, this book is dedicated, with friendly greeting, by the Author.

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MODERN SCIENTIFIC IDEAS

INTRODUCTION

A SUMMARY SURVEY OF FUNDAMENTAL IDEAS IN SCIENCE

If we were asked what were the fundamental ideas underlying modern science, I think we should answer Uniformity, Continuity, Evolution. A few words on each of these.

By Uniformity is meant the general sequence of cause and effect, the inevitableness of consequences, the absence of caprice, the general trustworthiness of nature. Given all the conditions, the results must follow. There is no self-will or rebellion among the atoms, nothing incalculable or capricious in their behaviour; they obey every force which acts upon them with promptitude and precision. Given the data, all their operations can be predicted.

All this has been and still is most conspicuous in astronomy. There the motions are of a comparatively simple character, and occur without much interruption or interference in fairly free space. Accordingly, the amount of calculation and prediction which is possible in astronomy has become almost proverbial; and the results predicted may be trusted to occur, provided that no data have been overlooked and all perturbations allowed for. Astronomical perturbations are always of the calculable kind, never of what may be called the human or capricious kind. The courses of the heavenly bodies are law-abiding and dependable, and the way to

make the calculations was shown us by Isaac Newton. It was his ambition to work out all phenomena in the inorganic world in the same sort of way, so far as they are not interfered with by the activity of life or mind. And the whole development of physics and chemistry depends upon this uniformity or trustworthiness of behaviour—what is called the reign of law and order, without variableness or shadow of turning; and it is in that faith that these sciences have attained their present enormous development. The uniformity of nature is a postulate or axiom based on experience, mainly unconscious and unformulated experience, as all our axioms are. They represent a thesis to which we have not found an exception, and in which, therefore, we have gradually grown into a complete confidence. The idea of the uniformity of nature is not one that can be proven; it is rather accepted. It is the foundation of physical science.

But then nature in its completeness contains not only the atoms of matter, together with heat, light, electricity, and other forms of energy which constitute the physical realm, Nature includes also life and mind, and possibly many other things of which at present we may be ignorant. The question arises whether uniformity applies to them also; whether their operations can be dealt with in the same manner if we had sufficient data; whether self-will, rebellion, and caprice can be eliminated from the universe if we had a sufficiently complete knowledge of it. Many have tried to see if they could answer this question in the affirmative, and they have done their best to bring vital phenomena into the same general category as physical phenomena, and to treat them all as subject to the law of uniformity. This is the basis of the Materialistic Philosophy. The attempt was entirely justified, but the results have turned out not very encouraging; and though there are some who still hope that the attempt may even yet be successful, the present tendency admittedly is to feel that there is something in the universe of a different order—some-

thing not calculable by any of the rules of physical science, that the power of prediction is limited not only by our capacity, but by the nature of things, and that the uniformity of physical nature can be interfered with by the real agency of self-determination and free-will.

What the ultimate truth in these matters may be, we must not be too confident and dogmatic. The science of any one era is the explanation of nature which has attained general acceptance up to that date, and at present it seems as if the behaviour of live things was governed by something other than or supplementary to the ordinary known laws. For instance, though an astronomer can calculate the orbit of a planet or a comet, or even a meteor, although a physicist can deal with the structure of atoms and a chemist with their possible combinations, neither a biologist nor any scientific man can hope to calculate the orbit of a common fly. And thus an incalculable element of self-determination makes its appearance quite low down in the animal scale, and we perceive that whatever may be the ultimate truth about uniformity, our formulation of it must not be pressed presumptuously and incautiously into regions of nature to which it does not apply. The introduction of, say, a spider into a galvanometer or other recording or measuring instrument would spoil its indications, and render them, at least in appearance, capricious. We may have faith that there is a reign of law and order even here, that chance at least has no footing, that all phenomena are explicable in terms of some data higher than those we possess. But admitting all that, we must also admit that there are many things in the universe which we cannot at present formulate, and to which we have not the clue. Always we must be guided by experience and be loyal to facts, whether we understand them or not. Science is young, and is confronted with very many problems which seem at present insoluble, though we may believe that the progress of discovery, ages hence, will find that they are

all ultimately intelligible, in harmony with mind, and amenable to reason.

Now take the idea of Continuity. At first sight things do not appear to be continuous. Every common object seems detached and independent of others. The pebbles on a gravel walk, the grains of sand on a sea beach, are all loose, detached, and disconnected from each other. The stars in the sky are also separate bodies, each apparently independent of the rest. Yet gradually we have learnt that they are not so independent as they seem. The moon is separate from the earth in one sense, but in another sense is attached to it, so that it has to remain at a fixed distance and revolve round the earth once a month. Similarly, the earth is attached to the sun. So also every pebble is attached to the earth, for if you raise it it will fall back again. We call the attachment gravitation, and we do not fully understand it. But we have gradually perceived that in that sense everything is attached to everything else. Every pebble attracts every other pebble, though truly with a force which is almost infinitesimal. Comets and meteors, which seem isolated and independent bodies, are all subject to the same connecting force. A piece of iron near a magnet, though apparently separate from it, feels, as it were, the threads of this attachment, and demonstrates in an interesting and conspicuous manner a special variety of the kind of action which is universal.

Thus the idea has grown up that there is a continuity running through the whole of material existence, that space cannot be really empty in the full sense of that word, but that there must be some continuous connecting medium to which all these linking phenomena are due. But just as we may have faith in an ultimate uniformity of nature, while yet we admit the existence of certain vital phenomena which seem with our present knowledge to run counter to it, so we find that, however strong our faith in an ultimate continuity may be, we yet

have to admit some striking examples of apparent discontinuity. And modern science has recently brought to light a great many examples of discontinuity, which are full of hopefulness and instruction, even though they seem puzzling in our present state of knowledge. The idea of discontinuity is one of the features of modern science, and a great part of this book will be occupied with examples of its occurrence. There is, as it were, a constant fight between continuity and discontinuity. Things which appeared discontinuous, like stars and pebbles and atoms, are ultimately connected or united by something which is by no means obvious to the senses, and has to be inferred. On the other hand, substances which appear continuous, like water and metals and rock, are found to be atomic in structure, and to consist of particles separate and apparently isolated from each other. Even electricity, which at one time seemed the most continuous thing known, is now found to consist of separate particles or small specks, to which the name electron has been given.

Continuity remains the fundamental idea to which scientific philosophy will in the last resort return; but meanwhile modern science is imbued with the idea of discontinuity, since it finds that all matter is composed of atoms, that electricity is composed of electrons, and that, however continuous the ultimate medium (the ether of space) may be, the energy in it seems to travel in separate discontinuous elements called quanta.

Thus it must be admitted that modern science is in a rather complicated, though very interesting, stage. In many departments we realise that we have not attained full knowledge, but are groping our way to it, and are encountering a number of facts the full explanation of which will need some generations of work on the part of our leaders. Meanwhile everyone can realise that the nascent or growing stage of a subject is a very interesting phase; and it may be possible to convey some idea of the present aspect of modern scientific ideas; though everyone not thoroughly trained in physics should realise

that the notions which they are able to form must necessarily be imperfect, inadequate, and incomplete.

The third fundamental idea with which modern science is suffused is Evolution—that is, the idea of gradual growth and development through long periods of time as opposed to the sudden production of results in a moment. The idea has been emphasised in the last half-century in all those sciences which deal with animate nature or the phenomena of life. In biology the term "evolution" is specially applied to the descent of animals and plants through a long chain of gradually improving ancestors from some primeval form; and the controversies that have arisen on the subject partly concern themselves with the stages through which each organism may have passed, and partly with the causes which have conduced to that gradual improvement. Some have attributed changes in the organism to changes in the environment under an inherent tendency to adaptation; some have attributed the gradual improvement or modification of species to the effort of each individual to make the best of his environment and to the inheritance of such acquired characters by successive generations; while others, again, have considered that only those creatures survived and propagated their species whose aptitudes, structure, and habits were such as could overcome the difficulties encountered, while those who were less favourably provided had gradually died out.

The differences of opinion have not been settled. But all agree that the process, whether of adaptation or of inheritance and survival, was a very slow one, that the intermediate stages were very numerous, and that the perfected organisms that we encounter to-day are the result of influences persisting through æons of time. Time, indeed, is of the essence of any process of evolution, even the most ordinary unfolding or development of any single individual life. For evolution may be treated as a very general term, signifying any process which goes on gradually in time. About the reality of a simple kind of

evolution it is unlikely that there can be any doubt, for the fact is forced upon our attention continually. No one supposes that a cornfield has sprung up in a night; everyone knows that it is the offspring of labour and time. No one expects fruit on a tree without its having gone through the intermediate stages of bud and blossom. No one imagines an oak without the antecedent acorn, nor a butterfly without the initial stages of grub and chrysalis. Remember, however, that none of this is biological or technical evolution. That concerns the slow methods by which animals and plants have become what they are; it traces their ancestry, and also endeavours to elucidate the bodily ancestry of man. In the realm of biology, however it be formulated, evolution is dominant.

So it is also in the realm of geology—

> The hills are shadows, and they flow
> From form to form, and nothing stands;
> They melt like mist, the solid lands,
> Like clouds they shape themselves and go.

Or in prose, an examination of the hills shows that they were formed beneath the sea, and have gradually risen through untold centuries to their present height, and in time will once more be submerged. The crust of the earth contains the remains of many creatures, the ancestors or intermediate stages of those which now exist. The rocks and the fossils are a museum of the past; they speak to us of the enormous tracts of time during which the earth was in preparation, was going through its evolutionary phases, times of greater violence than at present, till it became the habitable world it now is.

We see evolution going on in the heavens: the nebulæ breaking up into constellations; the stars radiating away their energy, partly to the planets which have been evolved round them, but mainly to some unknown factor in the depths of space; the gradual maturity and ageing of the solar system or systems, until it may be that they gradually grow cold and lifeless, unless they are blazed

up into activity again by some cataclysm, the like of which we also see occurring, every now and then, in unexpected and unforetold fashion.

It used to be thought, and is still sometimes taught, that all energy is running down and getting dissipated or frittered away, so that the activity, not only of the sun, but even of the whole material universe, must come to an end. But this idea of the dissipation or degradation of energy I do not put among the most fundamental of modern scientific ideas, for we are beginning to suspect that there may be a renovating or resuscitating cause, about which it is best to hold judgment in suspense. We cannot be sure that a cyclical or recurrent or periodic activity, continuing without cessation for ever, is not a characteristic of the material universe as a whole. Likened to a great Loom, from the oscillations of which there steadily emerges a woven fabric of beauty and design, the product or outcome of the periodic working of the material universe may be sought in a gradual increase or rise in spiritual values—a fluctuating, but on the whole progressive, improvement in higher and still higher qualities of life and mind—*magnum Jovis incrementum*.

The question arises whether evolution applies not only to living things and to the planets and suns in space, but also to the atoms of which matter is composed. Have they existed unchanged from all eternity, or have they, too, been built up by a gradual process from simpler ingredients? It is only of late that we have begun to ask that question. Fifty years ago we might have denied that the atoms were subject to evolution. Now we should certainly not deny, though some might hesitate to assert, that they were. The strong probability is that the electric units with which part of this book is concerned have paired off and built themselves up into atoms, not suddenly, but gradually, no matter how rapid some of the atomic processes may be. The further question will then arise, What was the origin of the electric units? We cannot answer. When we come to ultimate origins science is dumb; we are confronted with the problem of

existence, and if there is to be any solution of that, it is to philosophy and religion we must look and not to science. Science starts with certain data and traces what happens. It displays the universe as a continuous process, a constant evolution, a marvellous arrangement of law and order and beauty, which it cannot account for, but can only reverently study and admire.

Whether the time involved in evolution be long or short matters little. The element of time is essential to the idea. And that is a fact which may possibly have a bearing on our future outlook concerning evolution. For recently philosophers have begun to ask questions about the nature of time. Some imagine that it may be a human illusion; that the past and future are not non-existent, but only inaccessible; that by reason of human limitation we have to take things in regular order and succession, remembering the past, anticipating the future, but living only in the present. That we do this now is certain, that we could do anything else is barely imaginable; and yet human imagination has reached out even to that, and has supposed that a Being sufficiently high in the scale of existence could not only perceive the whole of the present as an instant, but could include the past and the future in a comprehensive survey, and that to such a Being the whole of existence would be an Eternal Now.

But with the Nameless is nor Day nor Hour;
Tho' we, thin minds, who creep from thought to thought,
Break into " Thens " and " Whens " the Eternal Now.

Manifestly we are out of our depth, and the speculation is only mentioned here for one reason—namely, as a caution not to be too dogmatic, final, and infallible about any of our ideas. When we were dealing with uniformity or regularity, we encountered a difficulty in the apparent operations of self-determination and free-will; when we were dealing with continuity, we encountered an apparently opposite element of discontinuity, which we shall find is at present a rather dominating modern idea; so

now when we come to evolution, or regular development in time, we are beginning to foresee that there may be a recondite difficulty about the nature of time itself.

It is instructive to realise these opposing ideas. We are always encountering conflict and opposition—friendly conflict, helpful opposition—all conducing to activity and stimulating thought. What we do not encounter anywhere is stagnation, blank and bloated satisfaction, final termination, complete attainment. We are always up against struggle and effort, of which the conflict of Good and Evil is perhaps the most conspicuous phase.

> No ill, no good! such counter-terms, my son,
> Are border races, holding each its own
> By endless war.

The great fundamental ideas need working out in detail. That may be said to be the object of the separate sciences. The details of biological evolution must be explained by a biologist, the problems of will and action by a psychologist. My province now can only be to take up the one idea of Discontinuity and apply that in some superficial detail; making it clear, once for all, that the knowledge of specialists goes far deeper than would be useful or appropriate in the present book. Treatises on these subjects are not easy, and can only be mastered by serious students; but every intelligent human being who calls himself educated can gain some general notion of the work that is going on and the tentative conclusions which are being arrived at.

Let us, then, without further preamble, pursue the idea of the atom in its surface aspects without attempting to go too deep, dealing first with the atom of matter as it was regarded last century, then with the atom of electricity, then with the atom of matter as it is regarded now. Next, let us diverge into the beginnings of chemistry from the modern point of view, and deal with the chemical atom; then try and penetrate into the ether to the atom of radiation; and, finally, indicate the way in

which the atomic idea can be applied to the problems of modern astronomy. For it is found that atoms give us information about the heavens, and that heavenly bodies, in their turn, give us further information about the atom. All these subjects could be expanded into a treatise, and possibly some of them even in this series will be so partially expanded. Discontinuity in various forms is the theme of the chapters following.

Thus it may be complained, and partially admitted, that whereas we set out with the ideas of Uniformity, Continuity, and Evolution as our theme, we have rather swerved from our promise and arrived or hinted at Variability, Discontinuity, and a deep-seated uncertainty about the nature of Time, which may cut at the root of the objective character of Evolution.

Very well, we are not stagnant, but in a state of flux; our ideas are those of the modern era, but there is no finality, no absolute completeness, even about our most fundamental conceptions. We creep from thought to thought, we delight in the findings of our day and generation, we hold up a gem or two for admiration, but no material explanation can be ultimately satisfying. When, for a moment, after a long day's survey of the field, we lift our eyes and gaze towards the spiritual horizon, we perceive a region beyond the scope of science, where measurements fail, where explanations cease, and we catch a glimpse of an unfathomed glory.

CHAPTER I

THE ATOM OF MATTER AS IT WAS REGARDED AT THE BEGINNING OF THE PRESENT CENTURY

THERE is no doubt that matter appears continuous. Anyone looking at a rock or a piece of iron would imagine that each particle was thoroughly joined up and in contact with its neighbours, that the whole substance was continuous, and that there were no gaps or empty spaces. Similarly, water appears continuous, and for a long time it was difficult to suppose that it consisted of particles at all. So the atomic or discontinuous view of matter had to make headway against a mass of ordinary experience; and even mathematicians, when they deal with flowing water, have what they call an equation of continuity which expresses the obvious fact that the substance flows continuously, without gaps or breaks or discontinuities of any kind. A similar equation is used when dealing with air and gases, though there the evidence of the senses is less conspicuous. Yet mathematicians know perfectly well that their treatment of continuity is an average treatment, and that it is only true because of the enormous number of particles which occupy any perceptible portion of space.

So we might speak of a meadow or lawn as a continuous plot of grass, without thinking of or attending to the individual blades. A haystack is a kind of unit, so is an ants' nest or a swarm of bees; and yet we know that if we choose to contemplate the individual constituents of which such a grouping is made up, it is quite possible to analyse or dissect it out into a multitude of units.

It is not so easy to deal with the individual atoms

which constitute a drop of water, because they are so excessively small and numerous that our senses, even when aided with the most powerful microscope, cannot detect any breach of continuity; the individual atoms are beyond our sense perception. Yet they have been counted, and their size is known. The number of atoms in a thimbleful of water is enormous, about the same number as the grass blades on the entire earth. It seems at first rather wonderful that they can be counted at all. So also it may seem difficult to estimate the number of grains of sand on a sea beach; but there is no real difficulty in making an estimate of that number, provided we know how many miles the beach is long, how many yards it is broad, and how many feet it is on the average deep. For we have only to estimate the number of cubic inches and then to count the grains of sand in, say, a tenth of one cubic inch —a thing which a child would be able to do. Scientific men are willing to take any amount of trouble to comprehend and express the facts of nature; and thus they have become able to specify the number of atoms in the whole earth, or, indeed, in the solar system, or any other mass of matter, however big.

But it may be said, How do we know that matter is atomic at all? How do we know that atoms exist if we never see them? How can we be sure that water is not *really* continuous? On that subject there has been much speculation since ancient times, but our knowledge of it became definite and metrical during the nineteenth century. The arguments for the existence of atoms—that is, of some units in matter which can be counted, as we might count the pips in an apple or the bees in a swarm —began to be cogent from certain facts in chemistry, discovered and formulated mainly by John Dalton at the beginning of the nineteenth century. He found that the chemical elements entered into combination in a perfectly definite numerical way; that when, for instance, hydrogen and oxygen combined to form water they did not combine haphazard, but that eight parts of oxygen, by weight, combined with each single part of hydrogen. And,

furthermore, that what was true of water was true of other chemical compounds. The elements combined in definite proportions; they were regulated by number; the combining ingredients could be counted, at least relatively. Common salt, for instance, is formed of 23 parts, by weight, of sodium combining with 35½ parts, by weight, of chlorine. Everyone knows that common salt is sodium chloride, but perhaps not everyone knows that the two elements, sodium and chlorine, must combine in that definite proportion or not at all. If there is an excess of one ingredient it will remain as an excess. There is neither excess nor defect in the compound formed; and this law is general, and is the foundation of the atomic theory of chemistry. To introduce the discontinuous unit, or atom, it was necessary to attach a specific weight to each variety. It was accordingly surmised that the atom of hydrogen, for instance, must have a certain weight, and that the atom of oxygen was sixteen times as heavy; so that when water was formed it must be formed by two atoms of hydrogen combining with one of oxygen, thus giving the previously known relative proportion of eight to one. And that was found to make a satisfactory and consistent scheme, so it became law.

So far this knowledge was only relative; it did not enable us to count the atoms themselves, only to specify their combining proportions. Then came the physicists, Lord Kelvin and others, who called attention to a number of physical properties which demonstrated that the atoms had an absolute weight and size which could be ascertained. One mode of doing this is by compressing a gas. Anyone would be ready to admit that a gas might consist of separate particles with spaces between them, because it is so compressible. When air is squeezed, as by a compression pump, the particles are driven closer together—some of the empty space between them is squeezed out; the particles themselves are not compressed, they are merely packed tighter. Any gas may be compressed enormously, say into the hundredth part of its

volume, but sooner or later there comes a limit. At first it is only like squeezing a number of indiarubber balloons; but if you go on squeezing them you will presently find an excessive resistance, when they are pressed so closely together that the actual substance begins to jamb. When you find that you can compress no more without excessive violence, the vessel is jamb full; the gas has practically become a liquid, the atoms have got into what may be called contact. By observing the force needed at the different stages of compression, a first estimate can be made of the size of the particles themselves. All the rest is interspace or comparative emptiness. There are innumerable evidences that a gas consists of separate particles, flying about at random, and that all we experience is the average of the combined activities of millions and billions of them.

But now take a liquid. What evidence is there that that has an atomic limit, too, and that if we could spread it out sufficiently, so that a single drop should cover an area of many square yards, it might become so thin that no more spreading was possible? There are ways in which a liquid can be thus spread out. When a drop of oil is put on a clean surface of water it spreads out at once into a thin film. When soap is added to water, bubbles can be blown, and those bubbles consist of a thin film of liquid. By optical devices it is possible to measure the thickness of such films; the thickness can even be estimated by the colours which the soap bubble shows. But a coloured film is not the thinnest film possible. If we watch a bubble closely as it thins down, we shall find (before it bursts) a patch devoid of colour, so thin as to be invisible, showing up, therefore, against a dark background as a black spot; and that black spot in the soap bubble is about the thinnest thing known. Recent evidence has shown that it consists of a number of soap molecules grouped together tightly side by side, with their length constituting the thickness of the film—rather like a wheatfield where the straw with its ears is standing vertically, making an apparently homogeneous sheath for

the earth below, each straw the same average length, which length corresponds to the thickness of the wheat crop, or, in the soap case, the thickness of the film. The film at its thinnest is one molecule thick, but a soap molecule consists of a dozen atoms in a column; hence, if we can estimate the thickness of the film, a twelfth part of that will be the size of the atom. Knowing the area of the film and its weight we can estimate its thickness, though optical methods are better for the purpose. In several ways the thickness of a soap film is known, and accordingly that is one way of determining the size of the atom.

We are regarding the thickness, or, rather, the extreme thinness, of the black spot in a soap film as a layer of molecules standing on end, each molecule like a rod of, say, twelve atoms in length. My intention is for you to think of the atoms in that instance as like a dozen little cubes, or very small dice, built one on top of another into a molecule, and then millions of these molecules or columns packed together side by side all over a table, so as to form a covering, or layer, or coating, or table-cloth one column of twelve cubes thick. This covering is to be taken as an absurdly magnified representation of the thinnest soap film possible. The dice represent the atoms; the whole covering represents the film. The thickness of the film is then to be measured, and so the size of atoms ascertained. But the very proper question arises, Are all atoms the same size? I reply, They are all of the same order of magnitude, though the atoms of heavy elements are slightly larger than those of light elements. (Molecules or groups of atoms may, of course, differ greatly in size; some may contain hundreds of atoms.) We should have to go into minutiæ to state what is now known about differences in atomic size, but roughly we may say that the difference between atoms of different kinds is like the difference between nuts of different kinds. All nuts are of the same order of magnitude, though some are hazel-nuts, some filberts, some walnuts. For rough general purposes we know what is

meant by the size of a nut—something bigger than a pea and less than an orange. To specify atomic size further would be possible, but complicated, for a lot of details are now known about it. I must leave it at that. I cannot say more about an atom until I have said something about electricity, because we now know that an atom is composed of electricity, and an immense amount is known about that.

There are innumerable other ways of making an estimate of the size of atoms, and they all lead to the same kind of result. By no one method alone should we be convinced, but by the converging testimony of a multitude of methods the scientific world has become convinced that atoms have a definite size and a definite weight, and that in any given portion of matter they can be counted.

And what is the result? It can be expressed in various ways. If a hundred printer's full-stops were placed side by side in a row, in contact with each other, their combined length would be something like an inch, or probably a little more. If we imagine ourselves able to deal with the atoms in the same way, and place them in a row, we should require 250 million to stretch the inch. Or, in other words, the number of atoms which lie on the surface of every square inch of a sheet of water are sixty thousand million million, while in a cubic inch the number is 250 million times greater. These numbers, however, are so great that they do not make much impression on the mind; they are beyond any numbers that we have to deal with in daily life.

Let us therefore express the facts in terms of some trace of impurity in the water. Sea water contains within itself any number of dissolved substances; among others it contains a certain very small proportion of gold, estimated at about one-fiftieth of a grain to the ton—not worth extracting. But if on the strength of this we choose to reckon the number of atoms of gold in a tiny drop of sea water we shall find an enormous number, more than fifty million. For the number of atoms in water itself is so enormous that the slightest trace of

perceptible impurity, even if it be but a million millionth of the whole, must consist of an enormous number of atoms. The number of atoms in a pint of water is far greater than the number of pints in all the oceans of the world. The lavishness and prodigality of nature is prodigious, for it is an undoubted fact that of atoms of this size the whole world and all the visible material universe is composed.

Another method of specifying their minute size, and therefore their enormous number, was devised by Sir William Crookes. The vacuum bulbs used in wireless telegraphy, and sometimes for incandescent lamps, are exhausted almost as far as instrumental means will allow, so that only a residue of a millionth part of the normal quantity of air is left in them; and yet the number of atoms that remain in is still enormous. If we could imagine exhaustion carried impossibly further, so that every atom was removed, and if they were then allowed to troop back again, through a leak so small that only a million could enter every second, the effect of such a leak could hardly be perceived for months or years; and if the leak continued, at that rate of a million a second, till all the atoms had returned, the time required would be of astonishing magnitude—thousands of centuries—comparable to the time that has elapsed since the geologic ages.

Thus, our first lesson, the result of the work of last century, is that matter is essentially discontinuous; that it consists of atoms of known size and weight, but that they are astonishingly small and numerous, almost beyond the reach of imagination.

These facts are not speculation; they are the commonplaces of modern science. Of these things our own bodies consist; every cell in a vegetable or animal body contains millions of billions of atoms; and the properties of a cell are so complex, the phenomena of life so mysterious, that in all probability this great number is needed to enable our bodily tissues to possess the structure they have and to carry out their respective functions. The human body

demands a certain number of cells, a very great but still a finite number; and each cell demands a number of atoms, also a very great but still a finite number. The size of the atom presumably determines the size of the cell; the size of the cell presumably determines the size of the body. Hence our bodies are related to the atomic ingredients of which they are composed, and the process of evolution has doubtless determined what is the best and most favourable size, for sufficient strength, and at the same time sufficient activity or power of locomotion. In determining that size, the gravitational force of the earth has, no doubt, been an effective cause. If a tree were too tall, the sap could not rise to its highest branches; consequently the height of a tree is limited. If an animal were too heavy, it could not move about, unless it floated in water like a whale. Presumably our own size is that which is best adapted to the exigencies of life on this planet; and accordingly here we are, with a fairly active, fairly beautiful, and yet sometimes rather troublesome body, which has to serve our time on earth.

CHAPTER II

THE ATOM OF ELECTRICITY AND SOME OF ITS PROPERTIES

Whatever was thought about matter throughout last century, there can be no doubt that electricity certainly was thought to be continuous. The term "an atom of electricity" would have sounded very odd, and Clerk Maxwell's great theory involved an equation of continuity. Yet occasionally there were flashes or intuitions, based upon certain facts, which pointed otherwise. Faraday discovered that a certain definite quantity of electricity was associated with every atom in decomposable chemical liquids; and found, moreover, that it was the same quantity, or simple multiples of that quantity—say two, or it might be three, instead of one—that travelled with the atom of every electrolytic substance. So that he apologetically and for the first time employed the phrase "an atom of electricity"—a phrase which Maxwell later, with a similar apology, adopted for this sort of chemical purpose, in connection with a travelling atom, though, as he said, it was out of harmony with all the rest of his treatise. He suggested, however, that the phenomena observable in liquids and gases might some day throw more light on the nature of electricity; and so, indeed, it has turned out.

Sir William Crookes was the first to call attention to the peculiar nature of what was going on in the rarefied gases of a vacuum tube under electric stress. He spoke of their condition as "a fourth state of matter," neither solid nor liquid nor gaseous, but something else, something more refined and ultimate. He made experiments on the stream of particles which are now familiar in what he called cathode rays—those rays which are flung off

from the negatively electrified terminal of a vacuum tube, and travel in straight lines with a speed and over a distance to which atoms of matter could not aspire. He did not indeed know that cathode rays actually consist of particles of electricity flying along at a speed not hopelessly short of the velocity of light, but that is what a few of his followers gradually perceived to be the truth. And these corpuscles or particles of electricity, before their nature was fully confirmed, were named "electrons" by a great, though barely known, physicist, Dr. Johnstone Stoney. And then in the closing years of the century the tremendous mathematical physicist, Sir J. J. Thomson, now Master of Trinity College, Cambridge, who had succeeded Maxwell and Lord Rayleigh in the Cambridge Chair of Experimental Physics, brought the whole phenomenon to book, and the clinching discovery that electricity was really atomic was finally and for all time made.

This he accomplished by treating the phenomena in the Crookes tube metrically and mathematically. By measuring the magnetic and electric deviations to which the stream of particles was submitted, his genius enabled him to weigh and measure these particles, to show that they were of one kind and one kind only, whatever kind of gas was admitted into the tube, and to prove that they were incomparably lighter and smaller than any atom of matter that ever existed. Thenceforth the electron took its place among the ascertained verities of science—a revolutionary discovery which has enthused and modified the whole of subsequent physics.

We now know that negative electricity exists in no other form than in these separate and extremely light and incredibly small particles. We harness them in the vacuum valves which most wireless operators use, and it is owing to their extreme mobility and docility that wireless speech has become possible. That, of course, was not the immediate outcome; that practical development was initially due to the discovery by Fleming that a stray observation of Edison's could be so developed as to detect

and display wireless waves in the simplest and most satisfactory manner. A valve acts in this manner, and serves this purpose, because the flying electrons can only convey negative electricity; they cannot convey positive. Hence they rectify the alternating pulses of the waves, transmitting the negative portions and suppressing the positive portions, not letting them pass; the result of which is to give a current, discontinuous, it is true, but all in one direction—a current which can be dealt with by ordinary means. The waves themselves, at the source, can be made as intermittent as we pleased; the train of waves can be cut up into longs and shorts of the Morse code, or, as was found later, they could have any peculiarities we pleased imposed upon them. Every feature of the train of waves could be detected and reproduced, the electrons moving with such speed and accuracy that they could follow all the fluctuations of human speech; and when the rapid electrical vibrations were transmuted into slower magnetic vibrations, those vibrations could operate the diaphragm of a telephone, and thus affect the human ear at almost any distance. For it must be understood that the speech to which people listen on the wireless does not travel as " sound " at all; it is not conveyed by matter, it is transmitted electrically by the ether of space. And it is only by certain ingenious devices, and by means of the electrons in a vacuum, that the emitted electrical oscillations, of an original frequency of some million a second, are reconverted into the audible frequencies of a few hundred a second, such as the voice originally produced at the distant end and such as the ear is competent to deal with. Hence it is that by radio transmission speech can be heard instantaneously—that is, within a small fraction of a second—even at the Antipodes, whereas if it were conveyed by matter it would take hours to travel, if, indeed, it could travel at all.

This, then, is one of the applications resulting from the discovery of the electron, but there are hundreds of others. We now know that every electric current in a

metal is a stream of electrons. We know that electrons can easily be torn away from atoms, so that by rubbing a piece of sealing-wax on a coat-sleeve, or by merely pulling a stylograph pen out of the pocket, electrons are torn from one substance and accumulated on another, giving the elementary and long known phenomenon of electric charge; though not till the present century did we know of what an electric charge really consisted.

If a thing has too many electrons, it is negatively charged, for the extra electrons are units of negative electricity. But we cannot manufacture electrons; we have to get them from something else, and the thing from which we extract them, having too few, is what we call positively charged. The pieces of matter with which we ordinarily deal have neither excess nor defect, but only the normal quantity which makes up the atom. Ordinary matter is, therefore, electrically neutral, but it is quite easy to disturb this neutrality; the slightest friction does it. We do it whenever we pull off our clothes, or brush our hair, or pass our hand over a sheet of paper, or when we rub anything out with indiarubber. But unless the clothes and the hair and the paper are specially dry, we do not observe any sign of electrification, because the tendency is for the electrons to return to neutrality immediately, by flowing back to the place whence they were extracted or disturbed. Most substances have sufficient electrical conducting power to allow this quick recovery, and so to spoil the demonstration, either by their own nature or by the slight amount of moisture which they contain. But by drying certain insulating substances —flannel, silk, glass, sealing-wax, etc.—the restoration to neutrality can be delayed; and the effort at restoration is then accompanied by electrical sparks, and by the other phenomena which in the laboratory are extremely well known. These effects were experimented upon long ago by Dr. Gilbert in Elizabeth's reign, who first called it electricity, and afterwards by Benjamin Franklin during the American War of Independence. He showed that this same tendency to restoration was responsible, on the

large scale of nature, for flashes of lightning between clouds and earth.

Friction is not the only way of disturbing electrical equilibrium; many chemical substances are able to disturb it, and make positive and negative charges travel in opposite directions. In that way was developed the voltaic primary battery, which produces electric currents by the tendency of chemicals to combine with each other. And if such an electric current is passed between metal plates immersed in a proper solution, electrical energy can be chemically stored and gradually given back as wanted—a process which we constantly use in the storage batteries or accumulators which excite our filaments, whether they be vacuum valves or electric lamps.

Faraday also found that electrons could be set in motion by moving a wire in a magnetic field, and thus discovered the dynamo, the mechanically propelled magnetic machine which generates the torrent of electrons that enable us to light our houses, propel our tramcars, and electrify our railways. The number of electrons which are thus set in motion in a conductor conveying these strong currents is enormous. It may be that each electron does not travel far; it may be passed from atom to atom, each atom only losing one and then gaining another, passing them on like a fire bucket from hand to hand. But the atoms are so numerous, and they conduct this process with such rapidity, that though each charge is incredibly small, yet the number is so great that one hesitates to say the number which even a thin copper wire can transmit.

It is true that in the process the atoms are perturbed a little, and made to vibrate by what they are doing, so that the wire becomes heated, and may even be melted if the current is too strong. Thick wire hardly shows this effect, but a badly conducting thin filament readily becomes dull red or white hot; and from such a filament not only light is emitted, but also a few of the electrons themselves are flung off. And it is these electrons, which evaporate from the hot wire, that we employ in the

vacuum valve; the process of electrical evaporation from a hot body being known as thermionic emission, a subject developed from a discovery by Frederick Guthrie fifty years ago, and one on which books have been written by Professor Richardson of King's College, London, and others.

Faraday called the electric transmitters "ions," meaning travellers. Ions in a liquid are atoms of matter, carrying one or two too many, or one or two too few, electrons; the two classes—the negative and the positive—travelling through the liquid at a slow pace in opposite directions. The ions in a gas are often the electrons themselves, and their rate of travel is prodigious. It is these which constitute the cathode rays, and it is by the behaviour of these extraordinarily light and quick travellers that J. J. Thomson was able to weigh and measure them, in ways of which it is difficult to give a popular explanation. Suffice it to say that if a magnet is brought near a stream of cathode rays in a vacuum tube, that stream is deflected or curved by a measurable amount, and if we know the strength of the magnetic field we can make deductions from the amount of curvature. If instead of a magnet an electrified body is brought near, they are again curved, this time by the electric field, which acts on them according to a different law, though the effect is not so easy to observe and requires much more skill. Still, these two separate deflections can be observed and measured, and the results submitted to mathematical analysis. The result is to give us, not only the speed, but also the mass of each individual particle, notwithstanding the fact that we are dealing with thousands and millions of them. And, furthermore, by collecting these particles and measuring the aggregate amount of charge responsible for a given current, it is possible to count them and determine the charge on each. The charge of a single electron is the fundamental unit of electricity, of which no fractions exist, so that this charge is the atom of electricity.

An electron, however, is only the atom of negative

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electricity. What about the positive variety? It cannot be that the positive charge is only the negation or defect of a negative charge; there must be some positive unit as well as a negative unit. And so it turns out. The positive unit is the heart and soul of the atom, as shall be explained soon. Less is known about the positive than about the negative unit, but they are certainly the same in amount. Electrically, they are equal and opposite. Mechanically, however, they are not, so there are still outstanding puzzles connected with the positive unit, though much more is already known even about that than was known ten years ago. The positive unit is called a proton.

Meanwhile it is the first discovered and negative unit which has opened our eyes to the discontinuous nature of electricity. Strange to say, there are now ways known of dealing with individual particles and of indirectly making them visible. To say that may be misleading; we can never really make an atom of anything visible directly, but we can make things visible from which the atom responsible for that appearance can be inferred. This indirect apprehension of things by inference is common enough. From an apple we can infer a tree on which it must have grown. From a bird we can infer an egg from which it must have developed, even though, as in the case of many animals, the egg is of extremely minute size, requiring a microscope to show it. From a finger-print we can infer a particular human being who made that print. So also from certain vibrations in the air we can infer an unseen orchestra and even some of the instruments which compose it. So again, it happens that from certain appearances, which are big enough to be seen, we can infer the presence and behaviour of single atoms or single electrons which have gone to produce those appearances.

Most of our science is a matter of inference. Very few of its phenomena appeal to the senses directly. The thing observed is often quite unlike the thing inferred. We have, for instance, no sense organ for the apprecia- tion of electricity and magnetism. We observe an electric

current by the deflection of a galvanometer, but the movement of a needle or pointer is not in the least like an electric current. The movement or rise of mercury in a capillary tube is not at all like a rise of temperature. The movement of a clock-hand is something quite different from a lapse of time. Most of our metrical observations consist in watching a pointer moving over a dial, but that same observation we can interpret in a multitude of ways. It may mean "time," it may mean "heat," it may mean an "electric current." The interpretation, like all our interpretations, is mental, and it is only by the skill of the experimental physicist, in devising and interpreting instrumental indications, that so large a number of the phenomena of nature have been brought thus indirectly within our ken.

If we press this idea into ordinary life we shall find that everything we observe is a matter of inference. A coloured patch on our retina is all that we directly get; but we interpret it as a landscape, or as cows in a field, or as snow mountains, or as a flower, or a picture, or, indeed, as another human being. So it is that we interpret certain phenomena as indicative of the otherwise hopelessly elusive electron or atom of electricity.

Perhaps the most striking method of displaying the presence of a single electron, and thus demonstrating even to the eye the discontinuous or atomic nature of electricity, is an experiment devised by Professor Millikan, then at the University of Chicago. He made a fine spray or mist of oil, of which the globules, which did not quickly evaporate, could be seen individually through a microscope, in a space between two horizontal plates, which could be oppositely electrified, with the positive plate above, the negative plate below. So long as any microscopic globule was not electrified, it took no notice of those plates, but merely fell under gravity. The fall was slow because of its minute size, and the rate of fall was measurable.

But the little globule or drop could be given a chance of becoming electrified by ionised air, when X rays were

turned on in its neighbourhood, or it could be diselectrified by exposing it to radium. And then what happened? Electrification was received and testified to by *jerks,* not by continuous movement. Directly the drop caught a single electron, it felt the force of the plates above and below it—the attraction of the plate above, the repulsion of the plate below. Its falling motion was suddenly checked, and might be converted into a rise. If the oil drop caught two electrons, it would give another sudden jerk and rise so much the quicker. Directly it was diselectrified it would fall steadily under gravity, as at first.

Thus, by alternate electrification and diselectrification a single drop could be kept under observation for minutes, or even hours. And the striking thing was that its changes of motion were always sudden. It manifestly did not receive any fraction of a unit charge; it received a whole unit, or else two units, or even three, but no fractions. The electric charge evidently did not exist in fractions, but in units that could be counted. Each unit of charge was an electron, and by measuring the sudden jerk or change of motion when an electron was captured, the amount of the electronic or unit of charge could be precisely determined.

What was happening was plain to vision. The eye, indeed, could immediately tell, without measurement, whether one, two, or three electrons had been captured. The change of speed caused by a single electron was quite definite, the change caused by two was twice as much, and so on. Hence, by watching the little oil globule and its sudden vagaries through a microscope, it may be said, not, indeed, that the electrons were visible, but that their effect was visible. The presence or absence of each electron gave a motion which could be observed, and the amount of that motion enables us to calculate the charge. The unit charge turned out to be the same as had been proved by Zeeman, of Amsterdam, to be responsible for atomic radiation, and again the same as that which was observed or inferred by Faraday as the atomic charge

when he decomposed liquids electrically. Thus all the evidence is confirmatory, and there is no doubt at all about the meaning of Millikan's experiment. This is indeed perhaps the best and most accurate method—it is certainly the simplest to understand—of all the methods which have been devised for measuring the unit of electric charge, the fundamental discontinuity in the universe, the electron or atom of electricity.

CHAPTER III

A BRIEF OUTLINE OF THE ATOM OF MATTER AS IT IS REGARDED NOW

Atoms being so amazingly small, as was emphasised in Chapter I, it seems incredible that they can have a structure, still more incredible that we can ever ascertain that structure and describe what is going on in the interior of the atom. Yet by the labours of those now living this amazing discovery has been made. An atom has been found to be quite a complex organism; it has been analysed and dissected into much smaller constituents, which were initially dealt with in the last chapter. And now I shall try to give some indication of how the atom of matter is regarded now, and of the astonishing constitution of ordinary matter thus revealed.

We have now learnt something about what electricity is like. It consists of innumerable little specks, little corpuscles, very much lighter than an atom, as an ounce to a hundredweight, and exceedingly smaller than any atom of matter, as a pea or even a mustard-seed to the Albert Hall. Strange to say, these corpuscles or electrons possess all the properties of matter and some more, some extra properties. We don't call them matter, because of those extra properties. It is those extra properties that attracted our attention; they are what we call electric or magnetic. The atoms of matter we knew by their other more ordinary properties; but the corpuscles have these properties, too, as well as their own special ones, and we now find that the atom of matter is composed of nothing else than these little corpuscles. These, as I said, are of two kinds: the positive unit of electric charge or proton, and the negative electric unit or electron. A certain grouping of these particles constitutes the atom of matter; and when the positives and negatives are equal in

number, so that they partly neutralise each other, their peculiar properties disappear or become masked, leaving only a residue apparent, which residual properties are those that we are familiar with in ordinary matter. Matter is, therefore, a neutralised kind of electricity; it has the properties common to both positive and negative; it is altogether less lively and active than electricity of either sign separately. It has only residual properties; though, indeed, many even of those are remarkable enough.

What we have to realise, and what we have only discovered in this twentieth century, is that the atom is wholly composed of electricity. It is a grouping of electrons and protons, and consists of nothing else. Matter has no existence apart from electricity, but electricity can exist apart from matter; it is much the more fundamental of the two. We learnt a great deal during the nineteenth century about the special properties of electricity, which are of extraordinary interest; and in the light of all that electrical information the atom has yielded up some of its secrets, and taken on a beauty and complexity which was previously quite unsuspected. The atom of matter used to be thought the ultimate unit, so extremely small that nothing smaller was imagined. That idea has been abandoned; it is built up of things very much smaller. To picture an atom as we now regard it, we must try to think of a minute proton at the centre and a group or family of electrons revolving round it, very much like the planets revolving round the sun, or what we call the solar system. The solar system is, in fact, like an atom on a gigantic scale—a heavy body at the centre, with lighter bodies revolving round it in regular orbits.

You must not think that because the electrons are so utterly minute they are moving at random or irregularly. There is nothing random in nature. They are perfectly obedient to law and order. Their orbits are known, and can be calculated, just as the orbits of the planets are known. The regular astronomy of the heavens is repeated inside the atom.

From the point of view of an electron, an atom is a big thing with plenty of room inside it; it is mostly empty space, like the solar system. It is immensely bigger than any of the particles which compose it—immensely bigger than the whole of them put together. The weight of the atom is the weight of the aggregate of particles, but the size of the atoms is far more than the aggregate of particles. If they were packed close together, the particles themselves would not occupy the millionth or billionth part of the bulk of the atom. The space in the atom is occupied by them, but only in the same sense as soldiers may be said to "occupy" a country. That phrase does not mean that they fill the country. A few soldiers with machine-guns might prevent access to a large territory. Their bodies would be as nothing compared with the space they in that sense are said to "occupy."

So it is with the constituent electrons in the atom. A foreign armed or electrified particle would be excluded. No one atom can encroach upon another, except with accompaniments of war and damage. But a neutral speck of infinitesimal size might penetrate and wander about in the interior of an atom without encountering any of the constituent particles, or only encountering them occasionally and at haphazard. So might a comet enter the solar system and pass through it without striking any planet. Just so could a stranger wander about on Salisbury Plain and think it almost uninhabited. He might be able to hail somebody at a distance, but he would be unlikely to bump into anybody. The same could not be said if his passage lay along Fleet Street. There the individuals are crowded close together, the space is filled with them, but there is no tight packing of that kind in the interior of the atom. The atom is mainly empty space, with just a few minute but very active particles pursuing their regular course within it. An atom is more like Salisbury Plain than Fleet Street.

This newly ascertained fact lays a fresh emphasis on what we said in the first chapter about the discontinuity

of matter. We there spoke of matter as atomic and therefore discontinuous, and said that in a gas the atoms were flying about as separate entities, colliding against each other at times, but otherwise independent, though we had to admit that in a liquid or solid the atoms were packed more or less together—packed so that they cohered whether they were in actual contact or not. It was, in fact, uncertain what we meant by "contact," for we did not then know what the constitution of the atom was. But now we see that however tightly the atoms are packed together, discontinuity is still the prevailing feature. Each atom is itself a discontinuous structure; it is not in the least like what we used to think it. It is itself mainly empty space, and its actual substance is confined to the comparatively few minute particles, at great distances from each other, which compose it.

In using terms about size and distance we have to speak relatively. An atom is very small compared with things we ordinarily deal with, but it is very large compared with an electron. In fact, the distances separating electrons inside the atom are as large in proportion to their size as the distances separating the planets. If the atom were magnified to the size of a cathedral, each component electron would be something like the size of a gnat. Twenty or thirty gnats in a cathedral would not occupy much space. Now abolish the cathedral and leave only the gnats. Let them fly round and round within its quondam walls, and you have a model of what the mental eye sees as an atom of matter, except that the regulated system of law and order, and many other important and essential properties, are absent from the model. The model only exhibits the relative size and fewness of the particles as compared with the empty space they occupy.

The question has been asked, What is the boundary of an atom? In other words, what takes the place of the walls of the cathedral in which the gnats are flying? One answer is, nothing. The atom has no material boundary any more than a solar system has. That is why

atoms can interlock or combine with each other and form molecules. A fuller answer would call attention to the electric forces of the flying electrons, their field of force, as if they were surrounded by impalpable elastic cushions, so that they are impenetrable to each other and can press against each other. It is here that the gnat analogy breaks down. All analogies must break down sooner or later, otherwise they would be no analogy but the real thing.

But now it is sure to be asked, You have told us how exceedingly small atoms are, and have given us some indication of how their size was ascertained, but how on earth is the size of the electron known? Our powers of imagination are being strained in conceiving things so incomparably smaller than the atom, and you have never even suggested any way of ascertaining their size. We understand from Chapter II that their weight and speed are known from observations of the deflection of flying particles in a vacuum tube, by applying the laws of mechanics to such particles, and by measuring the forces applied to produce a given deflection. We understand that this is done by a combination of electric and magnetic forces. The electric forces will act all the time, whether the electrons be in motion or not; whereas the magnetic forces will not affect the electrons when they are at rest, and will only act on them when they are moving at high speed so as to constitute an electric current. Thus we see that the laws of deflection in the two cases will be somewhat different, and we realise that from the electric and magnetic deflections, combined, something about mass and charge and velocity can be ascertained. But how does that give the size?

Well, as a matter of fact, that does not give the size. The size is a mathematical inference from the mass and charge. So long ago as 1881 J. J. Thomson showed that an electric charge must have mass or inertia of apparently infinitesimal amount, and that the more concentrated or compact the charge was, the greater would be its mass. No one supposed then that this could have

any practical bearing. But when the electron was discovered and its mass ascertained, it was perceived that that mass might be due to the electric charge and to the electric charge only; in other words, that there need be nothing in an electron but an electric charge, whatever that was, and that this might account for its whole mass. But to correspond with the observed mass an electron must be very concentrated; that is to say, it must be exceedingly small. By taking it small enough the mass could be accounted for by theory, but it would have to be exceedingly smaller than an atom. If electric charges are to account for the mechanical properties of matter, they must be exceedingly concentrated charges. The electricity cannot be diffuse; it must be concentrated into specks. Theory shows exactly how concentrated, and therefore small, those specks must be. The electrical theory of matter will only work if that is granted; the familiar properties of matter will only follow if the electron is frightfully small, and in that way the size is calculated. Everything confirms and strengthens the conviction that an electron is billions of times smaller than an atom.

Then Heaviside calculated that if an electron were in rapid motion, the magnetism generated would increase the mass to a certain definite degree; and after the discovery of radium it was possible to make experiments on particles ejected with such immense speed that this increase of mass became perceptible. The experiment was made by Kaufmann in Germany, with careful measurements, and the results agreed with theory. That is to say, the theory that an electron was nothing but an electric charge, of such curiously small size that its mass could be electrically accounted for, was verified and clinched.

It was thereby established, or not exactly established but rendered highly probable, that there was nothing in the atom but positive and negative charges; and everything since that date has gone to confirm this view, which is the basis of the electrical theory of matter, although still there is a certain outstanding puzzle about the nature

of positive electricity, the chief ingredient in the nucleus of atoms.

One thing, however, is a fairly certain outcome of both theory and experiment—namely, that whatever the size of an electron may mean—and until we know more about its structure we must not be too precise about its size—it is of such an order of magnitude or minuteness, its charge is concentrated into so small a compass, that the whole of its mass is accounted for; and thus the electron constitutes a fundamental unit, not only of electricity, but of matter.

I said before that 250 million atoms in a row would stretch something like an inch. I now say that 100 thousand electrons in a row would stretch something like an atom. Interpret these linear numbers in cubic contents, and you get some idea of the relative smallness of these things! The atom was incredibly small, the electron is billions of times smaller. But is that the limit? We used to think the atom was the limit of smallness. We now know that it has a structure, and is composed of things much smaller than itself. Has the electron also a structure, and will that be found to be composed of things much smaller than itself?

Yes, that is the direction in which things are pointing. We do not know the structure of an electron: we are here reaching the boundaries of present knowledge. Nothing smaller than an electron is known, but it is beginning to be vividly suspected.

Regarding the heavens, there seems no limit to size. In the other direction there seems no limit to smallness. At any rate, we have not reached a limit yet in either direction; possibly we never shall. The universe may be infinite in an infinite number of ways: it may be infinite in size, and also consist of things which are infinitesimal in smallness. It must contain things of which we at present have no conception. All we can do is to go on exploring, and thus stretch and enlarge the capacity of the human mind.

SUPPLEMENT TO PRECEDING CHAPTERS

ELEMENTARY EXPLANATION ABOUT INERTIA, MATTER, AND ELECTRICITY

Let us now sum up the main results of the preceding chapters. The atom of matter is not like what we used to think it was. It is full of emptiness. The cathedral has been abolished and replaced by a highly organised system of flying gnats. Matter has been resolved into a vast number of regular systematic assemblages of exceedingly minute electric particles. Hence it may be said that apart from electricity—which must be an affair of the ether—there is no matter. No one is denying the existence of matter, for it is practically the only thing that affects our senses; it exists all right, but we are resolving it into something far more fundamental. No one denies the existence of a cobweb—it can be seen and handled—but it is far from being an ultimate and permanent and unchangeable reality. What the ultimate reality is, what it will turn out to be, it would be premature to attempt to say. Before even guessing at an answer we must learn more about radiation and the ether of space.

Atoms are still the foundation-stones of the material universe, but our view of that material is changing; discoveries are flocking in, and neither this book—no, nor this century—will have the last word.

But before going further, some readers may be puzzled about the idea of " inertia " or " mass," and what that fundamental property of matter really is. There are things about it that are fundamentally puzzling, but to the general idea we have grown exceedingly accustomed ever since Sir Isaac Newton, and a few explanatory remarks may be helpful.

By the " mass " of a body we mean its massiveness, or

what is commonly called its weight—what is more accurately called its inertia. A thing of great inertia or great mass requires an effort to move it, even though it be otherwise freely supported by well-oiled wheels or by a cord or rope. A child could hardly move a railway truck even on a level line and even if there were no friction, nor could he stop such a truck if it were already moving. Matter itself is inert; no change occurs in it unless energy is supplied or withdrawn: otherwise its condition, whatever it is, persists unchanged.

This persistent tendency of matter is called inertia or mass. The mass of the earth and other heavenly bodies is enormous, and accordingly they travel steadily and uniformly in their orbits, unperturbed. Even to deflect their course needs great effort, prolonged over a considerable time. To stop a moving ship or a motor-car suddenly involves violence and damage. Inertia is a fundamental property of all matter, and it was shown by Sir J. J. Thomson that the same property must be possessed by electricity. An electric charge is surprisingly like matter in this respect. Even an electron requires force to start it, or stop it, or deflect its course. But it has the smallest inertia of anything known, and the force required to fling about an electron is therefore almost imperceptible. An electron is thousands of times lighter than an atom, and an atom is billions of times lighter than gossamer, or thistledown, or any feather.

Nevertheless, whether the mass be large like a planet, or small like an electron, the same law accurately holds; force is needed to deflect the course even of an electron, and it is by comparing the deflecting force with the deflection that the mass is ascertained. In astronomy the deflecting force is gravitation; it was Sir Isaac Newton who showed us how to deal with that, and how to measure the masses of the heavenly bodies. The only force known to act on an electron is either a magnetic or an electric force, or both together; and it was by a study of these that Sir J. J. Thomson showed us how to measure the mass of an electron. The laws of motion

are similar, or indeed identical, except that with electrons an electric field takes the place of gravitation. This fact has several important consequences, one of them being that the deflecting force is independent of the mass in the electric case, whereas in the gravitational case it is for some reason directly proportional to the mass. In the gravitational case the forces are enormous, but so are the masses, hence the changes in planetary movement are slow and stately; in the other extreme case, the electron, the forces acting on it are not infinitesimal, are not even insignificant, while the mass practically is, so the resulting movements are exceedingly quick—far beyond any other speeds we are acquainted with. But there is no difference in principle between the two cases: the calculations involved are similar; the Newtonian laws of astronomy can be applied, not only to the heavenly bodies, but also to the minutest objects known.

Not so long ago the question was an open one whether electricity really possessed any inertia. Attempts were made to find out if electricity was like matter in this respect; it was a problem which many physicists in the nineteenth century desired to look into. The truth was hidden from them, but it has been revealed to us. Electricity is found to possess all the fundamental properties of matter, and some in addition. We find that matter has no properties and no constitution apart from electricity, but that electricity can exist apart from matter. The additional properties possessed by electricity may seem a complication, but they are really a help. Every additional property seems puzzling for a time, but in the long run every new property discovered gives us new weapons of investigation and increases our knowledge.

Any moving mass of ordinary matter, like a cannon-shot or a cricket-ball, has certain well-known properties, but there is nothing magnetic about it. A moving charge of electricity, like a flying electron, on the other hand, is surrounded by a self-generated magnetic field. The magnetic properties of moving electricity enable us to make further deductions and give us a quantity of novel

information. That is why it has sometimes been said that we really know more about electricity than about matter. An electric charge has all the properties of matter and some additional ones, and it is by aid of those additional properties that we have learnt so much about it.

To understand the real nature of matter we must either try to split up the atom and deal with its constituent parts, or we must try to learn how and of what each atom is composed. This may seem hopeless, and indeed it is not easy; but an atom radiates, giving away some of its energy to the ether, and when we get energy in the ether it becomes tractable, we can analyse it and learn a lot about the kind of thing that emitted it. In that way we have found that an atom is wholly composed of electricity; and when we get down to electricity we feel at home and know what we are talking about. Electricity only exists as minute positive and negative charges, of size far smaller than an atom, and when equal numbers of positive and negative are packed together the result is neutral. That is how an atom is composed. It is really a complicated structure built up of an equal number of positive and negative particles. Normally, therefore, it displays no electrical properties, but it is easy to find some means of disturbing its equilibrium, breaking off some of its constituents, so as to be able to deal with them individually; and thus gradually we have almost proven that not only does the atom contain electrons and protons, but that it consists of nothing else.

This demonstration has now been accomplished to a surprising extent, and the result is that the atom has yielded up its internal secrets and has taken on a beauty and a complexity which was quite unsuspected throughout last century.

CHAPTER IV

THE CHEMICAL ATOM, OR THE MODERN VIEW OF THE FOUNDATION-STONES OF CHEMICAL SCIENCE

Chemists have long known that the multiplicity of substances which we encounter, both in this and other worlds, are all built up of a few elementary atoms. In fact, matter consists of molecules, each molecule being a group of atoms. A molecule may be a simple group of two or three atoms, like water, which is two atoms of hydrogen to one of oxygen; or like common salt, which is one atom of chlorine and one of sodium. Other molecules there are, like paraffin, which contain some dozens of hydrogen atoms, with about half that number of carbon atoms; or like sugar and wax, which contain oxygen in addition. Other molecules, again, like those of our own bodies, contain hundreds of atoms—hydrogen, oxygen, carbon, nitrogen—in a most complicated pattern—a pattern which may need the labour and genius of chemists of many generations to unravel. We now are not dealing with molecules—that would be far too complicated. Molecules are like edifices constructed of simple bricks. We are dealing only with the bricks, of which we now know that there are ninety-two different kinds. These are called the chemical elements.

We have to state, as far as we can, the way the atoms of the different chemical elements differ from one another. All atoms are built up of the same two fundamental units, but each kind contains a different number of units, and therefore the atoms differ remarkably in chemical properties. We have to seek for a physical explanation of the properties and behaviour of those elemental substances so long known and studied in

chemistry. It is wonderful how stable and definite the various groupings are. In spite of their astronomical constitution the atoms have till lately resisted all our puny efforts to change them or break them up.

Now the elements form a sort of family, each member having clear and distinctive properties, and the members are able to combine with each other, for reasons which have been long suspected and are now being established.

Roughly, the way that atoms are now regarded is like this. We recognise in them a central nucleus surrounded by a collection of orbits in each of which an electron is or may be revolving. Most of the orbits are nearly circular, but some few are excentric elliptical orbits reaching out to quite a distance from the nucleus. The one or two or three electrons in those far-reaching orbits are what make the atom specially active chemically.

The force which holds the atoms together in a molecule—the force called chemical affinity—turns out to be of an electrical nature. Some of the atoms are easily able to become negative, some naturally tend to be positive; or, as we might now say, some are liable to add to their constitution either one or two too many electrons, or to lose some and possess one or two too few, thereby in either case acquiring an electric charge. The positive ones then seek to combine with the negative, so as to restore the balance, and they link themselves together into a molecule by those outstanding electrical forces which we call chemical affinity.

The atom of sodium, for instance, has in its constitution a rather loosely hung electron revolving in an excentric orbit like a comet. This becomes detached when the atom is ionised, and then there is a gap or space for one electron more. Meanwhile, the atom is positively charged. An atom of chlorine, on the other hand, is easily able to acquire one electron too many, and thus to become negatively charged. Sodium with its deficiency, and chlorine with its surplus, can therefore fit into each other and combine, the combination being the neutral substance common salt.

Recent discovery has introduced us to a few substances of which the atoms have neither excess nor defect of electricity, being always neutral and therefore devoid of chemical affinity. These are the inert elements, the existence of which was unknown and unsuspected until, in 1894, Lord Rayleigh made the great discovery of the atmospheric gas argon, the first of the inert family known to science. This was a discovery of the first magnitude, and it was soon supplemented by Sir William Ramsay, who finely discovered the rest of the series. This inert or zero family has, as its lightest member, helium, and as its heaviest member the gaseous emanation from radium, an element which is able to remain gaseous in spite of the size and weight of its atom, because of its freedom from any unbalanced electric charge. The other members of the zero family, none of which form molecules, go by the names of neon, argon, krypton, xenon, and each of these zero elements forms the beginning or key-note of what has been called a chemical octave. Such an octave is a series of eight elements, of which the earlier members can easily become positive ions, while the later members of each octave can easily become negative ions.

To Newlands and Mendeléef we owe the first discovery of a succession of octaves running through the whole of the chemical elements. For when the elements were arranged in order of atomic weight and ingeniously subdivided into groups, it was seen that the properties of certain members in each octave had a strong similarity, though by no means identity, with those which occupied the corresponding place in the octaves below and above. The inert elements form, as it were, the key-notes of successive octaves; though in Mendeléef's time this fact had not yet been discovered.

First in the first octave, after the neutral and satisfied helium, comes the element lithium, with a single extra electron which can easily be detached, leaving it positive and ready to combine. First in the second octave, after the neutral and satisfied neon, comes the element sodium,

which also has a single detachable electron. After the neutral and satisfied argon in the third octave comes the element potassium, which is akin to sodium and lithium in its properties. At the other end of each octave we find also corresponding elements, with fierce desire for combination, but with a negative charge; fluorine in the first octave, chlorine in the second, bromine in the third, iodine in the fourth. All these can be happily united with either lithium, sodium, or potassium. To go further would mean the beginning of a treatise on chemistry. Suffice it to have adduced some typical examples.

The full meaning of the Mendeléef series and the total number of elements possible—between the lightest, which is hydrogen, and the heaviest, which is uranium (ninety-two elements in all)—was made clear by the remarkable discovery of young Moseley (who was killed in the war at Gallipoli) that the electrons which constituted the different kinds of atoms could be counted, and that their atomic numbers proceeded from 1 to 92 as the series was ascended. The atomic weights, which had previously given part of the clue, contain irregularities and complexities, the meaning of which has now been deciphered by Soddy and by Aston. The atomic weights are all whole numbers; there are no real fractions. Where fractions occur they are capable of explanation, sometimes a simple one, sometimes rather recondite. But the atomic number, emphasised by Moseley, is simple and straightforward; and whatever further discoveries are made, it is the atomic number which determines the chemical properties of the element, decides the combinations into which it can enter, and regulates its chemical behaviour.

That matter is electrically constituted, forms one of the greatest discoveries of the present century. Every element is built up of the appropriate number of electrons and protons—that is, of negative and positive electric charges. A proton is, for some unknown reason, much heavier than an electron: 1,850 times as massive, like a hundredweight to an ounce—a fact which constitutes a

challenge to future science, to the solution of which we have at present no clue.

Accordingly, these massive protons tend to congregate in the centre, interleaved by a sufficient number of electrons to hold them together in spite of their mutual repulsion. They thus form a massive nucleus, which determines the atomic weight of the atom; but the nucleus is positively charged, because it has too few electrons. That deficiency is supplied by an additional number, not fixed to the nucleus but circulating round it, after the same fashion as the planets revolve round the sun. In uranium there are ninety-two such planetary electrons, whereas in hydrogen there is only one. What we call the atomic number is, in fact, nothing more than the number of planetary electrons characteristic of the particular element. The nucleus itself has just that number too few. The atomic weight counts the number of protons in the nucleus. So naturally that, too, must be an integer, and it is often twice as big as the atomic number.

The atomic number of the common element carbon, for instance, so important a constituent in our own body and in our food, is 6, which means that each atom of carbon has 6 planetary electrons. But its atomic weight is 12, which means that its nucleus consists of 12 protons. Now the charge of a proton and an electron is exactly the same, though opposite in sign. Accordingly, it would appear at first as if the atom of carbon ought to be highly charged positively; but it is neutral, which shows that the 12 protons at the centre are interleaved or held together by 6 other electrons, immovably embedded in the nucleus, while the remaining 6 revolve in regular orbits round the nucleus. Similarly, the atomic number of the common atmospheric gas nitrogen is 7, while its atomic weight is 14. It contains, therefore, 14 protons packed together with 7 electrons, while the other 7 revolve round it and account for its chemical properties.

When two atoms combine, it must not be thought that the nuclei come close together. Atoms approach each

other only as two solar systems might approach each other. Any contact between them (if it may be called contact) is due to the approach and possible interlocking of their planetary systems, which extend far beyond the confines of the nucleus. The nuclei, the main substance of the atom, never approach within speaking distance of one another. They cannot until their planetary screen is torn off, and then their mutual repulsion will keep them apart unless a few electrons intervene.

It is possible that in some of the stars this actually happens, and that then the demantled protons, together with a few electrons, may pack themselves more closely together, giving a substance of extraordinary density, such as on earth we have no experience of. If we try to pack a portmanteau with a number of indiarubber balloons while the balloons are inflated and of full size, we can get very few in, and accordingly the density of the material in the portmanteau is but small. That is analogous to the condition of ordinary matter as we know it: it is mostly space, with a very little substance. But if we deflated the balloons, emptied them of air, we could pack an enormous number in. That represents the kind of condition that is now known to exist in at least one of the stars—a discovery for which the great astronomers of the present day are responsible. That star, the Companion of Sirius, is thousands of times denser than lead or gold. And what the properties of matter under those conditions may be we have barely any conception.

One way of bringing home the extreme rarity and porosity of ordinary matter is to say that if all the constituent electric particles constituting a human body were no longer separated from each other by empty space in the way they actually are, but were imagined as packed or crystallised together after the fashion of an atomic nucleus, the size of the human body, thus impossibly reduced, would be about as big as a grain of corn. Even if compressed more moderately, so as to be no denser than that peculiar star the Companion of

Sirius, a sixteen-stone man would be reduced to a couple of cubic centimetres, the size of a small walnut.

The fact is that most of the matter in the universe is at a very high temperature, so that the atoms are broken up. It is not usual to find them packed tightly together; they are generally diffuse like a rarefied gas. Our temperature on the earth is relatively very low. A low temperature is characteristic of any planet and of all bodies cool enough to give them a chance of bearing life. We are only a few hundred degrees above absolute zero; that is the sort of temperature to which we are accustomed, instead of a million or forty million degrees, such as exists in the stars. Under our low temperature conditions each nucleus is surrounded by a full atmosphere or screen of planetary electrons. Our earth atoms are therefore like the inflated balloons, and occupy much more space than they would seem properly entitled to. It is only under such conditions of low temperature that the heavier and more complex elements can exist. The chemistry of broken-up atoms must be simple: in fact there is hardly any chemistry, in the ordinary sense of the term, in bodies at excessive temperature; they consist of practically nothing but disconnected or dissociated protons and electrons. But as the temperature falls these fundamental ingredients of all matter fall together into groups, according to a system of laws which we have not yet ascertained, and thus the different elements are formed. The atoms then enter into combination with each other, and chemistry begins. Chemistry might be defined as the physics of complicated groups of protons and electrons, assembled in definite number and definite configuration, constituting the ninety-two chemical elements, of which by their mutual combination all material nature, as we know it, is composed.

Going back a little, it may be asked, Why do not the planetary and other electrons contribute to the atomic weight? Well, as a matter of fact they do contribute to it, as much as they can. But since each proton is 1,850 times as heavy as an electron (that is to say, is like

a hundredweight compared with an ounce) the few ounces cannot contribute much to an equal number of hundredweights congregated at the centre. Hence, so far as weight is concerned, the nucleus is the atom.

But chemistry does not deal with the nucleus, it deals with the planetary electrons; hence for chemical purposes, in spite of their slight weight, the planetary or satellite electrons and their number are the important things, although for many physical and all gravitational purposes the nucleus overpowers them in importance. To deal with the interactions of the planetary electrons is the task of the chemist, and is beyond our scope, though immense strides in that direction have been made by the singular genius of Bohr of Copenhagen and the many other physicists who have interested themselves in this great problem. To the mathematical physicists are due a number of reasoned out atomic pictures, of which a sample is sometimes drawn. Such a problem necessarily has at first to be attacked by physical means before it is handed over to the chemist. Chemists, indeed, do not find it easy to reconcile the new knowledge with their mass of ancient knowledge about the formation and structure of molecules, which has accumulated through the centuries. To apply the astronomical atom to chemistry is a task which might appal any but the most enthusiastic workers among the scientific chemists—a body of men who, with inadequate means and almost by their own unaided genius, had already discovered so much about the arrangements of atoms, whose constitution they did not know, into the complex organic molecules with which they are so brilliantly familiar.

To deal with the nucleus itself is the task of the physicist, and his progress in that direction is only beginning. Nevertheless, something is known about it, chiefly through the discoveries of Sir Ernest Rutherford and his co-workers. It is not easy to get at the nucleus in order to make experiments upon it; it is so well protected and screened. But by aid of the furious projectiles shot off by radium, Rutherford has found it

possible to bombard the nucleus with alpha rays or helium nuclei, which have a mass not incomparably small and a velocity incomparably great, so that the energy with which a nucleus can be bombarded is far from insignificant, and may be expected to produce striking results.

The difficulty, however, is to hit the nucleus. Its screen can be penetrated by the projectiles; the planetary electrons do not act as a screen to these massive alpha rays. Such rays go through the atom as if it were empty space, and the nucleus is so small that it seldom gets hit. Of ten thousand shots fired, on the average only one hits an atomic nucleus; but radium and similar substances can fire off thousands of shots a second, hence every now and then a hit is recorded.

When the nucleus is struck, something happens, and something very remarkable. The nucleus can be shattered by the blow, protons can be knocked out of it; and a single proton is identical with an atom of hydrogen shorn of its single planetary electron. Accordingly, Rutherford finds that hydrogen can be knocked out of many substances, though they previously contained no hydrogen. How can that be? Is the hydrogen created? No, it is like saying that smoke can be ejected from a pistol though it previously contained no smoke. It is probable that an atom of nitrogen can be smashed into hydrogen and helium. The atomic weight of helium is 4, the atomic weight of hydrogen is 1, while the atomic weight of nitrogen is 14. An atom of nitrogen might therefore possibly consist of three atoms of helium with two of hydrogen ($3 \times 4 + 2$); that would make up the number 14. We do not know that it is so; we only know that when nitrogen is bombarded and shattered, hydrogen makes its appearance, probably helium too. The hydrogen is recognised by its extensive range of flight, for it can be caught on a zinc sulphide target a long way off. And this sort of thing, which is true of nitrogen, is true of many other substances; the nuclei can be shattered into simpler ingredients. This

is a path of discovery on which we have only recently begun to set our feet.

In old days Ebenezer Prout made the hypothesis that all matter might be built up of hydrogen atoms. We now think that they are all built up of hydrogen and helium atoms. There is a further possibility that helium itself may be built up of hydrogen, so that Prout's hypothesis, a century old, may be justified by future results. But we have not yet learnt how to build up atoms; we can only shatter them to pieces, and that with difficulty and on a very minute scale. All that we can say for certain at present is that all material substances are built up of the two fundamental electric units, the proton and the electron, whose own intrinsic constitution it remains for future science to discover.

Innumerable things remain to be discovered about the chemical atom; but some things are already known, and we have indicated some of the lines on which advance may be expected, and to which the energies of workers all over the world are now actively directed. What the practical outcome of these researches will be it is too soon even to speculate. That there is an immense store of energy within the atom is certain. That it will ever become accessible to humanity is doubtful. If it did, or if ever it does, the amount of energy derivable from the mere chemical combination into molecules called combustion, of which we make so much use at present, will fade into insignificance, and presumably coal and oil will become things of the past. That time is not yet. We ought not to be wasteful of the sources of energy now available, even though we may hope that they may be superseded by something cleaner and better. Even coal can be burnt cleanly if we take sufficient trouble. Chemical methods of obtaining energy may give way to more powerful physical methods some day; meanwhile it behoves a civilised nation to economise its resources, to extract all valuable by-products, to keep its atmosphere pure and healthy, and to regulate its methods of combustion wisely and well.

CHAPTER V

THE BEGINNINGS OF THE INTERACTION BETWEEN MATTER AND ETHER, OR ATOM OF RADIATION

We now come to a part of the subject which, though full of a most important and unexpected discontinuity, will probably be harder than any of the rest. The reason for that is clear enough: no one can explain with complete satisfaction a thing which he does not clearly understand himself. There are points about radiation discovered during the present quarter-century which are puzzling, and which no one yet completely understands. It is easy enough to say that radiation is light, or just like light, and that surely we understand about light. But that is just the difficulty: we don't. Scientific people know a terrible lot about it, and last century we were inclined to think we knew nearly all. But now, in face of unexpected difficulties, we have grown more modest, because we have learned still more.

We used to think that light was a mechanical vibration in the ether. We knew its speed, its wave-length, and all about it. All that remains true; there is nothing the matter with light as a vibration except that the mechanics of ether vibrations won't work out perfectly. There seemed something wrong with mechanics, or what mathematicians call dynamics, when so applied. Then Clerk Maxwell taught us that the ordinary mechanics of force and matter, and the ordinary laws of motion, were off the track; that though light was truly a vibration in the ether, travelling at the speed and with the wave-length that we knew, it was not a mechanical vibration; that, in fact, everything in the ether was purely electrical or mag-

netic, or both. Light is an electric vibration of the ether, not a mechanical one. The ether may be able to explain mechanics; mechanics cannot explain the ether. That is where we stand to-day. Light cannot be explained in terms of the dynamics of matter. The dynamics of ether are different, and are not yet known.

Maxwell's electromagnetic theory was a most brilliant discovery, and revolutionised our treatment and theory of light and of radiation generally. Before that we had not even known how to generate or produce radiation of any kind. We could only do it indirectly by making a body hot. When hot enough, everything began to glow and was visible in the dark. We knew that light emitted by red-hot or white-hot bodies must consist of ether waves, but we did not know what was happening in the hot body, nor did we know how to produce such waves otherwise; though the glow-worm did. A glow-worm would be most uncomfortable if its tail were red-hot! We were puzzled. After nearly a quarter of a century of study, Maxwell's theory enabled us to generate ether waves artificially, directly and intelligently, by purely electrical means. Hertz and I were working at them, and succeeded simultaneously in directly producing and detecting ether waves, in 1887 and 1888, in laboratory fashion. Hertz, indeed, got them advancing in free space, unguided by wires. This is done now on a large scale at every wireless sending station. And we have learnt that atoms emit light in a manner somewhat similar, though on an exceedingly different scale.

All this being so satisfactory, wherein lies the difficulty? How can we say that we are less thoroughly satisfied about light, now, than we were last century? We have all the information of last century at our back; it is all true as far as it goes, and we have more in addition. Yes, but it is just the more in addition that confronts us with those puzzling features that I hinted at.

Light is able not only to excite the retina of our eye,

and affect the chemicals on a photographic plate, it can also eject one of the planetary electrons from an atom, so that it jumps right away; and we find that the speed or energy of that ejected electron depends not at all on the strength or intensity of the light which ejected it, but simply and entirely on its wave-length. If we multiply the energy of ejection by the wave-length of the light which causes the ejection, we find that we get an absolute constant, the same for every atom, for every kind of matter—a new and quite unexpected constant of the universe. This constant, now called the quantum, was discovered by Max Planck of Berlin, at one time President of the University there. It is a discovery which enters fundamentally into all atomic physics, and has had both informing and puzzling consequences.

It is not difficult to see why there should be something puzzling, and at present barely intelligible, about the subject of radiation. As long as we deal with matter and atoms alone, we can get along happily enough. As long as we deal with the ether alone, as we did in last century's treatment of light, we are on fairly easy ground—easy at least to the great mathematicians and physicists who solved the problems of interference and diffraction and polarisation, etc., for us. But in the production and absorption of radiation, we are dealing with neither matter alone nor ether alone; we are dealing with the interaction of the two. That is where the unsolved problems lie.

We do not accurately know the structure of either ether wave or electron, but as long as we dealt with only one we could slur that over, taking the electron as the absolute unit in one case and the wave in the other case. But now when we try to combine the two, and exhibit or dissect out the constitution of the atom, or the electron rather, and the wave—the structure which enables it to eject an electron—when we try to understand how an atom can emit or absorb radiation, we come across this unexpected and mysterious fact, that (in atomic emission or absorption) energy and wave-length are intimately con-

nected; their product is constant. If the electronic energy effect is great, the wave-length is small; if the wave-length is great, the energy effect is small. The size of the one factor exactly compensates for smallness in the other factor. How can this be?

It does not occur on our large-scale artificial methods; it only occurs where the atom is concerned. But then light, and all the ordinary radiation that we deal with, is produced by atoms and is absorbed by atoms. Hence we are up against this curious constant, which is called the quantum. It is evidently very important, but it is at present unintelligible. If we understood the structure of the ether, and also the structure of an electron, we should, I am sure, understand the quantum; but we don't. So naturally, when I try to explain a thing that I do not properly understand, the result is difficult of apprehension. Ten or twenty years hence the difficulty may evaporate; or perhaps complete understanding may take longer, perhaps a century. Meanwhile it would not be honest to try to conceal our ignorance. What we are sure of is that there is some meaning in the phrase " an atom of radiation." Let us see if we can gain any idea about it at all, without yielding to premature speculation such as only Masters in science may indulge in.

Elementary Considerations

When a bullet or other projectile strikes a target, so as to be suddenly stopped, its energy must be accounted for somehow. It is accounted for partly by the noise of the impact, partly by the flash which a large projectile can produce, but mainly by the heat developed, either in the projectile or target or both, by reason of the concussion and disturbance and subsequent vibration of the molecules.

Sir William Crookes found that even a single atom can produce observable effects; and in the hands of Rutherford this has enabled many facts about the behaviour and construction of an atom to be inferred. One

striking effect produced by a single atom, when projected with sufficient speed, is the luminous splash which it causes on a target of a phosphorescent substance, such as sulphide of zinc. We cannot artificially project particles with sufficient speed; but they are spontaneously ejected from substances like radium, in what are called alpha rays. These rays consist of helium nuclei—a compact group of four protons welded together by two electrons—projected in enormous numbers, with a speed far exceeding anything that can be artificially produced. At these enormous speeds any particle of matter, however small, has great energy; and accordingly the blow an alpha particle deals is sufficient to cause a chemically prepared target to emit a flash of light where it impinges; and a succession of hundreds and thousands of such splashes is what causes the usual phosphorescence on a screen exposed to radium. To see the individual flashes a microscope has to be used, and with instrumental aid the flashes can be counted; so by setting the screen at different distances the *range* of the projectile particles can be measured, and thereby Sir Ernest Rutherford has been able to make many important deductions. Thereby he claimed to prove that he had smashed the nucleus of a nitrogen atom.

An electron flies at still higher speed, and can be stopped very suddenly by an obstruction; consequently when a single electron strikes almost any target, it, too, can emit a flash of something akin to light. For Röntgen found that a high-speed electron, striking a massive target so as to be suddenly stopped, emits a splash of X rays. That is the way in which X rays are produced. A massive target of some heavy metal, like platinum, is put in the path of a stream of cathode rays in a vacuum tube, like those devised and constructed by Crookes but more highly exhausted, and the stream is caught as a target catches bullets. Each electron, as it is stopped, emits into the ether a single pulse, which spreads out from that centre like a ripple on a pond when a stone is thrown in. The aggregate effect of such pulses, from

a vast multitude of electrons flung by electrical force against a target, constitutes the ordinary beam of X rays, of which so much use is made in surgery and medicine.

Light, and X rays, and all radiation, consist of ether waves of varying wave-length or frequency of vibration. X rays are known to be only a variety of radiation, of a wave-length much shorter or a frequency higher than the waves of light. We can have radiation with waves of any length, from the comparatively slow vibrations used in wireless telegraphy (which for a 300-metre wave is a million a second) up to the vibrations of yellow light, which are 500 million million per second, and on to X rays, which are many thousands of millions of millions per second; and so up to the gamma rays of radium and other radiations, of which the extreme limit of frequency is not yet known—if, indeed, there be a limit. All of these waves travel at exactly the same speed, the unique ether velocity, the velocity of light. Meanwhile the most familiar kind of radiation is common light, the light of common day. It consists of radiation from the sun. The term "radiation" is a generalised name for light. Long-wave radiation can be generated artificially, as Hertz discovered, and is used in radio telegraphy; but most kinds of radiation are very small waves emitted by processes which go on inside the atom of matter.

In dealing with atomic processes a second is a long time, during which all manner of things may happen. A second bears the same relation to atomic processes that a millennium of a thousand years bears to the actions of human or individual history. In fact, the number of vibrations per second which go to constitute ordinary visible light is vastly more than the number of seconds which have elapsed since the Christian era or since the building of the Pyramids. The seconds would have to be counted back into the Geologic Ages, twenty million years ago, before the tale was complete of the number of waves that enter the eye in a single second. There is something in the retina of the eye which is able to deal, probably quite indirectly, with vibrations of this

tremendous rapidity. It is such vibrations which affect the chemical substances in a photographic plate, so as to record an impression of the source which has emitted or modified them. Radiation, in fact, brings us all manner of information about what is going on at a distance. It is by radiation that we see a landscape; radiation from the heavenly bodies tells us about their size and distance, and even about their chemical composition and their temperature.

But how do we suppose that this radiation—ether waves from the sun and stars—originated? The only fully analysed source of radiation is the sudden stoppage of high-speed electrons. Ether pulses are produced by the jerk of their stoppage. May we take that as a model of what is happening generally? May we assume that all radiation is emitted in jerks, by reason of some collision, or drop, or collapse, or other sudden change in the interior of an atom? We could not assume such a thing without evidence; but the evidence is forthcoming, and that is what we are learning as the truth.

It appears probable now that the emission of radiation is not a continuous process, but a discontinuous or jerky one, analogous to the sound emitted by the blow of a hammer, or the clash of cymbals. That is the beginning of the meaning of the quantum.

It has been ascertained that when an electron is moving it is surrounded by a magnetic field. When it is stopped, what becomes of that field? The answer is, It turns into radiation. Every time an electron changes speed, its magnetic properties, which depend on that speed, must change too; and if the change be very sudden, energy must be either emitted or absorbed in perceptible quantities.

Now inside an atom each electron moves in a regular orbit; it may move in any one of a selected set of possible orbits, but, strange to say, it need not keep to that one orbit. On Bohr's theory it may suddenly jump from one to another, as a bird hops up or down from its perch. If it hops down it emits a quantum of radiation of

definite wave-length. That same amount of radiation, provided it is of the same quality, may make it hop up again.

Briefly, that is an account of what occurs. Every time an electron drops nearer to its centre or nucleus, a pulse of radiation is emitted. Every time a pulse of radiation is received and absorbed, the electron which absorbs it jumps up again. Unless it jumps it cannot absorb energy. If it absorbs energy it must jump. That represents the mutual reaction between ether and matter. Some of the energy which was in the revolving electron, part of the energy of the atom, has gone away into the ether; but some of it has gone in such form that when the pulse encounters another atom it may make a precisely similar electron jump away from its centre and proceed to revolve in a higher orbit, or even escape altogether.

There is still some mystery about the process; it is not fully understood, but the evidence is strong that these discontinuous orbits exist, and that every time an electron jumps from one to another a quantum of radiation is emitted. The characteristic thing about radiation is that it is emitted and absorbed in quanta discontinuously. Not because of any discontinuity in the ether or in radiation itself, but because of the utterly discontinuous character of the atomic structure and the countable or unitary character of its electronic constituents.

Thus we see that the discontinuity of matter and electricity has, strangely enough, invaded the province of the ether of space; and so, in spite of the continuity of that medium, it is affected by the jerks inside the atoms. much as it submits to the fluctuations artificially impressed upon it by the vagaries of human speech at a sending station. It patiently receives the results of the atomic jerks, just as it can be made to receive the waves modified by human speech or music; it perfectly conveys the jerk, or the speech, to any distance, and there, in due course, it allows the original disturbance to be reproduced by a suitable receiver. The listener-in hears the

speech and the music by tuning in to the right wave-length. The receptive atom somehow feels the jerk of the ether pulse coming from a long way off, and in response to one particular wave-length, out springs one of its energetic electrons. The atom does not seem to be attuned to the wave-length, nor does it care how feeble the wave is—and yet, when the right wave arrives, out jumps an electron with exactly the same energy as was possessed by the distant and alien electron which generated that particular wave. A most puzzling phenomenon, well worthy of study! All I can say now is that it is the kind of thing that has made us begin to speak about a corpuscle or atom of radiation, and has introduced that unexpected discontinuity, the quantum, into the relationship between ether and matter, and therefore into the scheme of nature.

CHAPTER VI

IMPORTANCE OF THE ATOM IN ASTRONOMY AND COSMOLOGY, OR THE COSMIC ATOM

We talk of the astronomy of the atom, for an atom is like a star or a solar system; it is a central nucleus with a family of planets. A molecule is like a constellation; and any ordinary piece of matter is like the Milky Way. Astronomy helps us to illustrate the atom, the atom is helping us to understand some things in astronomy; and, rather strangely, there are newly discovered facts about the internal structure and temperature of stars which give us further information about atoms. The two provinces of knowledge, apparently in every sense so far apart, act and react on each other.

First let us deal with the simple resemblances and differences of structure. Each atom consists of a minute central body or nucleus, corresponding to the sun, surrounded by a family of electrons, definite in number for each particular chemical element, which revolve in regular orbits round the central nucleus, in close analogy with the movements of the planets—Earth, Mars, Jupiter, and the rest—round the sun. One difference is that in the atomic case all the planets or electrons are quite similar or interchangeable with each other, whereas the astronomical planets differ considerably in size. Another difference is that the orbits in which the atomic satellites can move are few and definite in number; though after all this difference may be more apparent than real. We do not know as yet what law it is which regulates the distances of the earth and other planets from the sun. Neither do we know the reason of it in the atomic case. But the fact that the radii of atomic orbits are regulated by the squared simple numbers

1, 4, 9, 16, 25, etc., seems to be clear enough; the only uncertainty is *why*.

There are atomic analogies not only to the planets, but even to the comets, for some of the possible orbits in the atom are very excentric, just as they are in astronomy. The possible orbits are regular and determined, but every possible orbit need not be occupied by a revolving body. Those possible orbits which are not occupied by any satellite may become occupied by an electron which is captured, or by one which has jumped up or down from some other orbit. For the odd thing is that each planetary electron does not always adhere to the same orbit, as a planet does; it occasionally drops from a higher to a lower, or occasionally jumps from a lower to a higher. What makes them drop we do not know, but every time they drop they emit a quantum of radiation; for they cannot drop without disturbing the ether, as a stone disturbs the surface of a pond, and out spread the ripples, stimulating the eye or a photographic plate. We don't know what makes the electrons drop towards the nucleus, but we do know what makes them jump up further from it, though we don't know why or how. It is the ripples that do it; as if the ripples made by the drop of one stone into a pond could make another stone jump out of the water—a process which seems absurd in the pond case, not absurd, but strange and unlikely, in the atom case. It seems unlikely because we haven't the clue, though we must admit the facts. We find that when certain waves encounter a suitable atom, they can expend a quantum of energy in making an electron jump out, or at least jump from a lower position to a higher one. It is just that sort of power possessed by the ripples that is puzzling us about the nature of light, as I hinted in the last chapter, for there is a surprising connection between energy and wave-length. Any wave-length too long has no effect, but if a wave is the right length it causes a fully energetic result.

Now let us make these jumps and drops of electrons more definite. They can be made very definite, but I

must not attempt too much. There are a limited number of possible orbits round the nucleus of an atom, and they are arranged in a regular and known series; but some of these orbits may be empty sometimes, while at other times they may be occupied by an electron which has jumped up or dropped in or has been captured as a stray.

Hydrogen, for instance, the simplest of all the elements, has one proton at the centre and one electron revolving round it, normally at a distance of a hundred thousand times the size of either of those bodies, as if each particle were an inch across, like a halfpenny, and the distance between the two halfpennies was about a mile. One halfpenny revolving round another a mile away in a big circle; that is a magnified model of a hydrogen atom. But that is not the only possible orbit in a hydrogen atom; it is the smallest one. About thirty other possibilities are known, and among the multitude of atoms in any ordinary portion of hydrogen gas the electron of some atoms may be revolving still further away in one of these other orbits, especially if the gas is rarefied.

It may be asked how we can possibly know which orbit an electron is in. We do not know so long as it remains steadily in that orbit, for it is placid there, and gives no sign; but directly it jumps from one orbit to another it gives us information. For it cannot jump without emitting or absorbing a quantum of radiation; that is to say, it cannot make a sudden movement without disturbing the ether, and that disturbance appeals either to our eyes or to a photographic plate. The radiation can be analysed by the spectroscope; its wave-length can be measured, just as we can measure the wave-length emitted by any given wireless station. By measuring the wave-length we know which station it is that is emitting the wave; we can say, that is Cardiff, or Glasgow, or London, or, it may be, Daventry or Paris if the wave is very long. In the same sort of way, though by different means, by aid of the spectroscope or right kind of wave-

meter, we can infer both the orbit an electron has jumped from and the one it has jumped to. For the wave-length indicates precisely the energy of the jump. The orbits can be numbered, and the radiation tells us when there has been a jump from number four to number three, or *vice versa,* or perhaps a bigger and more energetic jump from number four to number one. Every jump is associated with a certain definite frequency or wave-length, and so, though we cannot observe the movements in the orbits themselves, we can tell every time they jump. We can specify which orbit they have come from and which they have gone to. All this is done by the evidence of the spectroscope, and the amount of information thus obtained, though it requires great skill and experience to disentangle its meaning, is due to measurements of astonishing accuracy and precision, which have left no serious doubt about what it is that we are really observing.

If it were not for these alternative orbits, a simple element like hydrogen could not give a complicated spectrum—a whole lot of wave-lengths—but as a matter of fact it does. It gives a spectrum consisting of a series of bright lines such as the eye can readily see, and it gives other series which can be photographed but which cannot be seen; indeed, from the theory of the jumps such a series was predicted by that remarkable genius Niels Bohr, now of Copenhagen, before it was observed. Astronomy is well known to be an accurate and clearly understood science, by reason of the exact predictions which are familiar to everybody. And the same is true in atomic astronomy, except that the predictions are by no means familiar to the general public. They have been the work of men of genius engaged in the calculations associated with spectroscopic observations.

A spectroscope is only an instrument which sorts out the waves and places them in positions corresponding to their size, the short waves at one end of the scale, the long waves at the other, each set of waves producing its own bright line or visible representation. The spectro-

scope is, in fact, a wave-meter. We use wave-meters in wireless, and at present we have to adjust the wave-meter until it responds to or indicates some particular wave. No such adjustment is needed in the spectroscope; it gives us by simple inspection, supplemented by careful measurement, not one wave only, but a whole series simultaneously. And thus we get full and complete information about all the jumps which are taking place. The indications have to be deciphered, the instrument read, say by Professor A. Fowler at South Kensington and other workers in Great Britain and on the Continent and in America who are expert at this kind of observation. Wireless experts are not the only experts. Spectroscopic experts have developed a facility and an experience which eclipse all our performances.

It is sometimes speculated whether our wireless waves, generated here, can ever reach other celestial bodies and give them information. However that may be, there is no doubt that the waves of light generated in the heavenly bodies reach us and give us information. The waves we receive are not several hundred metres in length; they are waves comparable to the millionth of an inch. No matter for that; they can be dealt with even more conveniently and completely than long waves.

Thus we get information, not only about the chemical composition of the heavenly bodies, but a mass of detail also about what is happening in their very atoms. We know not only the kind of atom responsible for a given series of waves, but the occurrences that are going on in that atom and the temperature to which it is subject. Thus atomic astronomy has illuminated cosmic astronomy to a surprising and almost overwhelming extent. And cosmic astronomy is reciprocally beginning to teach us something about atoms.

Looking at an ordinary piece of matter with the eye of science, we now see it as something like the midnight sky. It consists essentially of a multitude of separate discontinuous bodies, each very small and at relatively great distances apart, which are each in a state of rapid move-

ment — sometimes continuous and regular, preserving their energy unchanged, but occasionally executing a spasmodic movement which disturbs the ether, emits an atom of radiation, and thereby tells us what is happening. We learn about occurrences in the heavens in the same sort of way; not indeed by mere inspection, any more than we see what is going on in a piece of matter by mere inspection, but by instrumental detection, measurement, and inference. The heavenly bodies are obviously detached from each other, but they are all immersed in the ether, and any process occurring at their surface facing us gives us a sign. They, too, like matter on the earth, consist of protons and electrons. Most of them contain these bodies in a simpler state of aggregation than those we are accustomed to down here. The processes there are really easier to follow, and much more is known about the interior of a star than about the interior of the earth. There they are—the stars—exposed to the gaze of our big telescopes and all the other instruments which can receive and analyse the light which they emit. Except for atomic clashes they would not emit any light. All radiation is due to the jerks of electrons inside the atoms, or it may be to the collisions of electrons and protons with each other. Whenever there is clash, like a chemical clash, waves are emitted—ether waves—of measurable length. It is a kind of wireless telegraphy going on on a tremendous scale, but mainly executed by exceedingly small radiators, so that the waves are of excessively short wave-length. The radiation is prodigious in quantity, and appears continuous, but that is only because of the multitude of radiators. Each pulse is really discontinuous, the radiation is emitted and received in quanta; that is to say, in definite or, so to speak, atomic portions. And when the radiators are sufficiently detached and separate from each other, they give a bright line spectrum, which is full of information.

Matter on the earth is much denser and more crowded, the radiators are packed closer together and interfere

with each other—at least when the condition of the matter is solid or liquid. Only when our terrestrial matter exists as a gas, and preferably a rarefied gas, does it give a bright line spectrum which we can analyse. Otherwise, when packed tightly together, they give a continuous spectrum, like a rainbow, wherein by mutual interference the waves are of innumerable grades, and cannot be sorted out clearly and distinctly. It is as if a station like Rugby had a large number of radiators in a small area, each emitting its own definite wave, but so numerous and so interfering that nothing could be made of it at a distance. The jumble of waves would not then convey any definite message; there is no tuning in or tuning out of a continuous spectrum. There would be no definite wave-lengths to measure or receive; the result would be confusion, though certainly, in the optical or rainbow case, a confusion of much beauty.

But it may be said, That surely happens in the case of the sun. Surely the atoms there *are* tightly packed together and the spectrum is continuous. True, that is so. But now comes in the converse phenomenon. The atoms can not only emit, they can absorb, just as our collecting aerials absorb radiation. And each aerial can be tuned so as to receive only one wave-length, or at least to receive that more easily than any other. The atoms in the solar atmosphere behave like collectors or absorbers or receiving aerials. Light of a particular wave-length is absorbed by them, and consequently we do not get the continuous spectrum emitted by the main dense body of the sun without sophistication. The light which reaches us has been filtered through the solar atmosphere and through our own. Some wave-lengths have been extracted and suppressed or quenched by the atomic receivers in the sun's atmosphere; and wherever a wave-length is absorbed, there we shall find a gap, a dark line in the spectrum.

For the atomic satellites can not only jump down and emit, they can jump up and absorb. Wherever a dark line exists in the solar spectrum, we know that there

must have been atomic absorption; we know that an electron has jumped up from one orbit to another in a particular kind of atom. We can specify the kind of atom and we can specify the kind of jump. If an electron cannot jump, it cannot absorb any radiation: it can only jump by receiving a definite wave-length; but if it does receive that wave-length and does absorb it, it will quench that particular kind of light from the sun. We shall see a spectrum crossed by dark lines, by reason of the jumps up, and they will be in exactly the same position as would have been emitted had the jumps been down. So long as we get definite indications of wave-length it does not matter whether we get it by a bright line or a dark line; the information given is the same. Whatever an atom can emit, that also it can absorb. We may receive either emission spectra or absorption spectra. One is as good as the other, and both enable the same inferences to be made from the indications of our wave-meter or spectroscope.

But it may be said, Are the lines which we observe in the spectrum always accurately in their right position? Is there nothing which can change the wave-length slightly as it travels? The answer is not completely No, for it is possible for the quanta of radiation to encounter free electrons as they travel through space, and thus be made to rebound with a slightly changed wave-length. But then those portions which rebound will not reach us direct, so that for all practical purposes the answer is No. The direct wave arrives unchanged in length, as it was emitted.

But suppose it were emitted by a moving body, one which was either approaching or receding; there would be a change then. For it is well known that a railway whistle may be heard about a semitone either above or below its true pitch when a locomotive is either approaching or receding. And that does happen in light also. But it is not a single line that will be thus shifted; it will be the whole series of lines emitted by a definite kind of atom. And accordingly the effect does not

introduce confusion, it gives us additional information; it enables us to infer how fast the source is approaching or receding. It tells us this even about the most hopelessly distant stars, too faint to be seen even in a great telescope, and only able to be photographed by hours of exposure; and thus we get information which at one time there was no hope of our attaining.

The inferences drawn by the human mind from the waves received through the ether are multitudinous. Such inferences are not really more surprising than those which we are accustomed to make—too familiarly accustomed—when we look at a landscape and at the moving objects in it. From the patches of colour on the retina we infer all manner of things almost without effort. In a similar way, though with effort, with instruments, and with much skill and experience, astronomers are able to decipher what is occurring in the heavens.

Modern astronomy is becoming atomic in a surprising sense, just as the atoms themselves have become astronomical. There is a unity running through the whole of material creation; the atoms in the earth and the atoms in the cosmos are linked together by the same laws. The whole is a magnificent system of law and order. The unity of design running through the whole universe is complete and conspicuous to those with eyes and minds developed enough to perceive and deduce from the phenomena the underlying realities.

And there is something further to be said. Our particular cosmos, which we see as the Milky Way, consists of a vast multitude of stars, most of them only visible in a large telescope. Each star is an enormous body, and their number is prodigious; each is a sort of cosmic atom, and the whole gigantic system, though large beyond imagination, constitutes a single compact system, a sort of cosmic unit or grouping complete in itself, and far away from any other assemblage. Yet in the depths of space, at distances at which the imagination reels, we catch glimpses of other independent systems, far, far distant, of which the spiral nebula in Andromeda is one. That

nebula, faintly visible to the naked eye, we now know to be a cosmos as big as our own; and what may be going on in that awfully distant region, who can guess? Many extraordinary things happen even on the surface of this tiny planet, where we plan and contrive and hope and love and live our little day, and probe into mysteries which we cannot solve. Depend upon it that there is some Mind that really comprehends the whole, that can attend to the smallest detail—to every human being, to every bird, every sparrow—and can yet feel at home in the infinitude of space. Nothing too small, nothing too big, for that infinite Mind's understanding and fostering care.

No one looking at the self-acting machinery in a workshop, however automatic the working may seem, could do otherwise than infer a mind which had designed and constructed the whole. Still more do the splendours of observation and inference, now possible to man, speak of an all-controlling and all-designing Mind. There is no chance, nothing haphazard, in any part of the universe. It is a manifestation of law and order and beauty, which appeals to our highest faculties; and, in moments when we can realise even one aspect of that revelation, overwhelms us with wonder, love, and praise.

BIBLIOGRAPHY

General

Continuity: Being the Presidential Address to the British Association in 1913 by Sir Oliver Lodge, with explanatory notes (J. M. Dent and Sons).

Elements of General Science, by Caldwell and Eikenberry (Ginn and Co.).

A First Course in Physics, by Millikan and Gale (Ginn and Co.).

Science for All, by several writers (Ward, Lock and Co.).

Soap Bubbles, by Vernon Boys (S.P.C.K.).

On the Cosmic Side

Pioneers of Science (a biographical history of astronomical development from earliest times), by Sir Oliver Lodge (Macmillan).

The Vault of Heaven, by Sir Richard Gregory (Methuen).

A Voyage in Space (Six Lectures adapted to a Juvenile Auditory), by Professor H. H. Turner (Sheldon Press).

And slightly more advanced and more systematic:

Popular Astronomy, by Simon Newcomb (Macmillan), or, more recent, *General Astronomy,* by Spencer Jones.

On the Atomic Side

The ABC of Atoms, by Bertrand Russell (Kegan Paul).

Atoms and Rays, by Sir Oliver Lodge (Benn).

And more advanced:

The Structure of the Atom, by Professor E. N. da C. Andrade (Bell).

References to Quotations in this Book

P. 15. Tennyson, *In Memoriam.*
P. 16. Virgil, *Fourth Eclogue.*
P. 17. Tennyson, *The Ancient Sage.*
P. 18. Tennyson, *The Ancient Sage.*

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